C6 New Data / Global Land Data Assimilation

Summary

Accurate knowledge of land-surface moisture and energy stores in coupled Earth-system models is critical because of their regulation of surface water and energy fluxes between the surface and atmosphere over a variety of time scales. Subsurface moisture and temperature stores exhibit persistence on seasonal-to-interannual time scales. Together with surface forcing and land-surface dynamics, this persistence has important implications for the extended prediction of climatic and hydrologic extremes (floods and droughts). Because these are integrated states, errors in land-surface forcing and parameterization accumulate in these stores, which leads to incorrect surface water and energy partitioning. This is especially true for long-term global reanalyses. However, many innovative new land-surface observations are becoming available that may provide additional information necessary to constrain the specification of land-surface states. These constraints can be imposed in two ways. First, near-global observations (e.g. precipitation and radiation) can be used as forcing for a land-surface model in order to provide land data consistent with the real world (and avoid inherent numerical weather prediction biases). Considerable effort has already been put forth improving the quality of these meteorological forcing data for use in global land modeling efforts. Second, by employing innovative land-surface data assimilation techniques, observations of land-surface stores (such as soil temperature and moisture, and snow) can be used to constrain unrealistic simulated storages. Land data assimilation schemes also have the potential to maximize the limited land-surface observations by propagating their information throughout the land system to unmeasured times and locations.

The general strategy followed by the DAO is incremental. Atmospheric assimilation systems until quite recently have had such large biases in cloudiness, precipitation, and sometimes temperature, that any potential impact of assimilation of land-surface quantities was obscured by these biases. Therefore, we have carried out experiments to understand the sensitivities of the land-surface model and to identify the most important parameters to improve in the atmospheric assimilation. We have also developed strategies to use the land-surface system to help validate the physical integrity of atmospheric parameters. Another approach is to fuse products from the atmospheric system with independently prescribed data sets (e.g. precipitation and surface radiation) to improve the forcing of land-surface variables. The ultimate goal is assimilation of state variables of the land-surface model, and then having these interact with the atmospheric system. Because of the complexity and the uncertainties involved, we feel that this incremental approach allows careful investigation with a reasonable expenditure of resources.

Research exploring the optimal simulation of the land system in NASA's Goddard Earth Observing System (GEOS) Data Assimilation System (DAS) using relevant remotely sensed observations within a land data assimilation framework is underway. Research with the Mosaic [Koster and Suarez, 1996] Land Surface Model (LSM) is proceeding in two directions. First, Mosaic has been interactively coupled with the GEOS-DAS (see Part B Section I.1). Second, land-assimilation system development, integrating the Physical-space Statistical Analysis System (PSAS) with Mosaic, continues

with the Off-line Land-surface Global Assimilation system (OLGA) project. The off-line development of modeling and assimilation techniques is computationally efficient for long-term studies of the impact of the integration of observations and model data on land-surface prediction. Eventually, the OLGA system (shaded oval in Figure 1) will be integrated into the GEOS assimilation system.

Improved Hydrology and Interannual Variability using OLGA

In order to better understand the implications of the Mosaic model in the GEOS DAS, we have examined the model in offline experiments where Mosaic forcing is derived only from GEOS-1 DAS data (accepting that significant errors exist). We have compared (Figure 2) temperature and specific humidity anomalies from observations (Gaffen and Ross, 1999), OLGA and GEOS-1 DAS for 1981-1995 over the central United States. The observations indicate an average distribution of dry/cool and warm/wet anomalies, following the Clausius-Clapeyron relationship. However, the observations show significant events that do not follow the Clausius-Clapeyron relationship and are instead warm/dry or cool/wet episodes (the red and blue dots off of the linear relationship depicted by the green pluses). Extreme warm/dry episodes, such as the drought of 1988, and extreme cool/wet episode, such as the flood of 1993, represent important geophysical phenomena, which must be better represented and forecast. Because of the prescribed surface moisture in GEOS-1 DAS, there is continual moistening at high temperature revealing the linearity of the Clausius-Clapeyron relationship at all times in GEOS-1. Neither the 1988 drought nor the 1993 flood is well represented. Therefore, the GEOS-1 land parameterization had apparent difficulty handling water stressed conditions. With the self-consistent water budget in OLGA, the 1988 warm/dry water stressed conditions are represented. OLGA represents the general variability of the land-surface even when the atmospheric forcing terms are as biased as GEOS-1. These profound changes from the introduction of the land-surface model place reveal the foundation of the improved results in the GEOS-3 reported in Part B (Section I.1.

Monthly mean hydrology data from OLGA and GEOS-1 have also been used to drive a global river routing model (Miller et al., 1994; Bosilovich et al. 1999). The river routing model computes river flow from modeled precipitation and evaporation, which can be compared with observed river flow. Results indicate that most of the river basins show smaller errors in river discharge for OLGA hydrology compared with the GEOS-1 DAS (Figure 3) related to better reproduction of evaporation and snowmelt processes (details discussed by Bosilovich et al. 1999). It is important to note that this OLGA case uses only GEOS-1 DAS data as forcing, and better results are expected from more current products.

The Influence of Observed Forcing on Land Surface Predictions

The river routing results and the interannual variability of temperature and moisture indicate that even though the GEOS-1 forcing may be biased, improvements in land-surface data can be produced simply by using a higher quality land-surface parameterization. In order for a land assimilation of state variables to be most effective, however, we must minimize the systematic biases in the state variables. Precipitation and radiation (critical forcing components of the land state) can have large errors in the GEOS-1 DAS related to large spatial variability and representation of cloudiness. Other sources of forcing data from satellites, either used independently or merged with the GEOS-1 observations, help to reveal the sensitivities of the land-surface model. This also allows identification of the most important parameters in the GEOS assimilation system to improve for land-surface applications. By using remotely sensed observations of precipitation and radiation to provide forcing for OLGA, we should be able to generate estimates of land-surface parameters that are consistent with the observations as well as the land-surface model, thereby improving land-surface data that could be used interactively in the GEOS DAS (as well as the state variables that will be assimilated). Here, we are examining the impact of using observed precipitation and radiation on the OLGA system.

The Mosaic Land Surface Model (LSM) [Koster and Suarez, 1992, 1996] was run in an off-line mode, for the global land-surface for all of 1992, using forcing from near-surface meteorology from the GEOS-1 reanalysis and precipitation and radiation from other sources. The precipitation observations were derived from the polar SSM/I microwave instruments the DMSP (Defense Meteorological Satellite Program) satellites. The global surface radiation flux was derived from the International Satellite Cloud Climatology Project (ISCCP) compilation of polar orbiting and geostationary visible and infrared observations. The OLGA results were validated using surface skin temperature observations derived by ISCCP.

The first 3 panels of Figure 4 show the difference in the land-surface net longwave and shortwave radiation, and precipitation forcing between observations and the GEOS-1 GCM. The second 3 panels show the improvement of the surface temperature predictions when observations are used as forcing, relative to predictions made only with GEOS-1 GCM forcing.

These results show, that on the yearly average global scale, forcing OLGA with observations improves the prediction of land-surface temperature. However, the improvement varies greatly in both space and time, often being quite significant on the diurnal time scale and in highly localized areas. There remain significant differences between the model predictions and observations of surface temperature. It is thought that bias in the surface air temperature prescribed by the GEOS-1 model have a significant amount of control over the surface skin temperature. Therefore, to further improve land-surface temperature predictions, biases in surface air temperature must be addressed. It was also observed that the land-surface model performance improves more when the entire surface radiation balance is observed versus when only one component of the radiation balance is observed. Finally, contrary to expectations, observed precipitation has only a very slight impact on surface temperature. It is likely that observed precipitation does have a significant impact on other land-surface predictions (e.g. soil water and evaporation).

Assimilation of Land-Surface Temperature

The ultimate goal of this research is the development of land-surface assimilations (surface temperature, soil water and snow depth) using the PSAS package. Assimilation of land-surface state observations in OLGA system is limited by (1) the general lack of global land-surface state observations, and (2) the unphysical nature of many of the parameterizations in land models. Surface temperature is the most mature land-surface observation and is well suited for assimilation because observations are readily available from geostationary satellites, and its modeled representation is relatively physical. But, the small memory of this state (on the order of several minutes) limit its effectiveness. A methodology for assimilating surface temperature, as derived by ISCCP, has been developed in OLGA using the PSAS package, and preliminary results of this method are shown in Figure 5. This methodology includes anisotropic error covariances, and in the near future will include a bias correction of the land-surface model at each time step and will be implemented in a coupled mode. The impact of this assimilation experiment is relatively small; however, it is only the first step in the development of more comprehensive capabilities.

References

Bosilovich, M. G., R. Yang and P. R. Houser, 1999: River basin hydrology in a global off-line land-surface model. *J. Geophys. Res.*, 104, 19,661 - 19673.

Gaffen, D. J. and R. J. Ross, 1999: Climatology and Trends of U.S. Surface Humidity and Temperature, *J. Climate*, **12**, 811–828.

Koster, R. D. and M. J. Suarez, 1992, Modeling the land surface boundary in climate models as a composite of independent vegetation stands, *J. Geophys. Res*., 97, 2697-2715.

Koster, R. D., and M. J. Suarez, 1996: Energy and Water Balance Calculations in the Mosaic LSM. NASA Technical Memorandum 104606, Vol. 9.

Miller, J. R., G. L. Russell, and G. Caliri, 1994: Continental scale river flow in climate models. *J. Clim*., 7, 914 – 928.

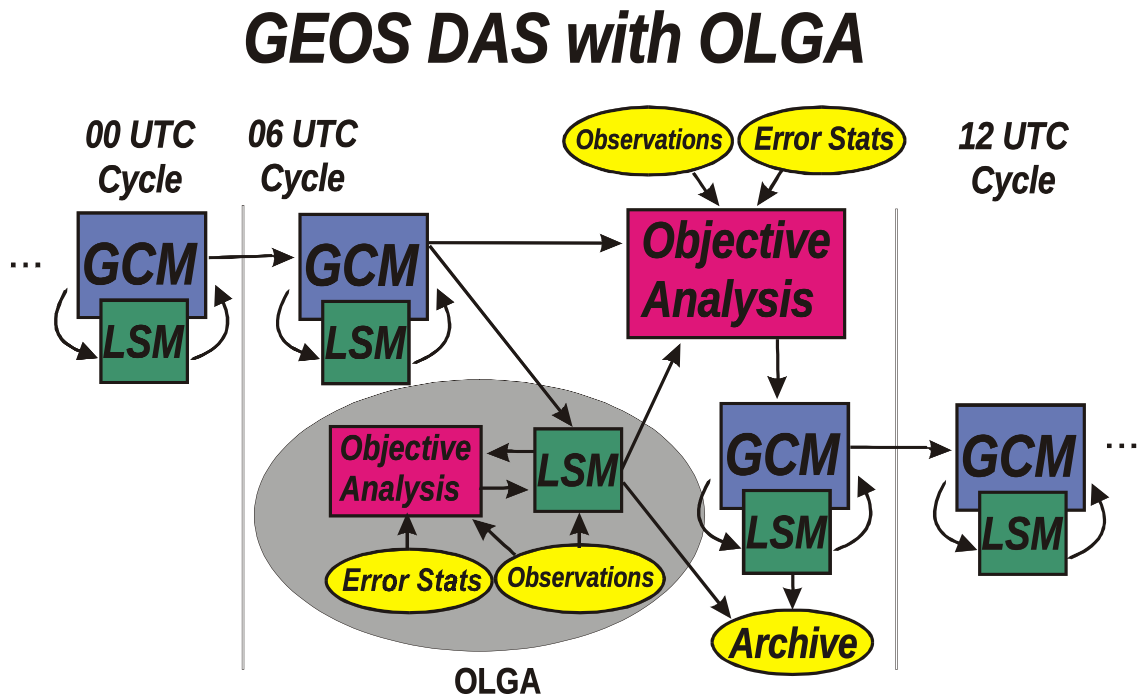
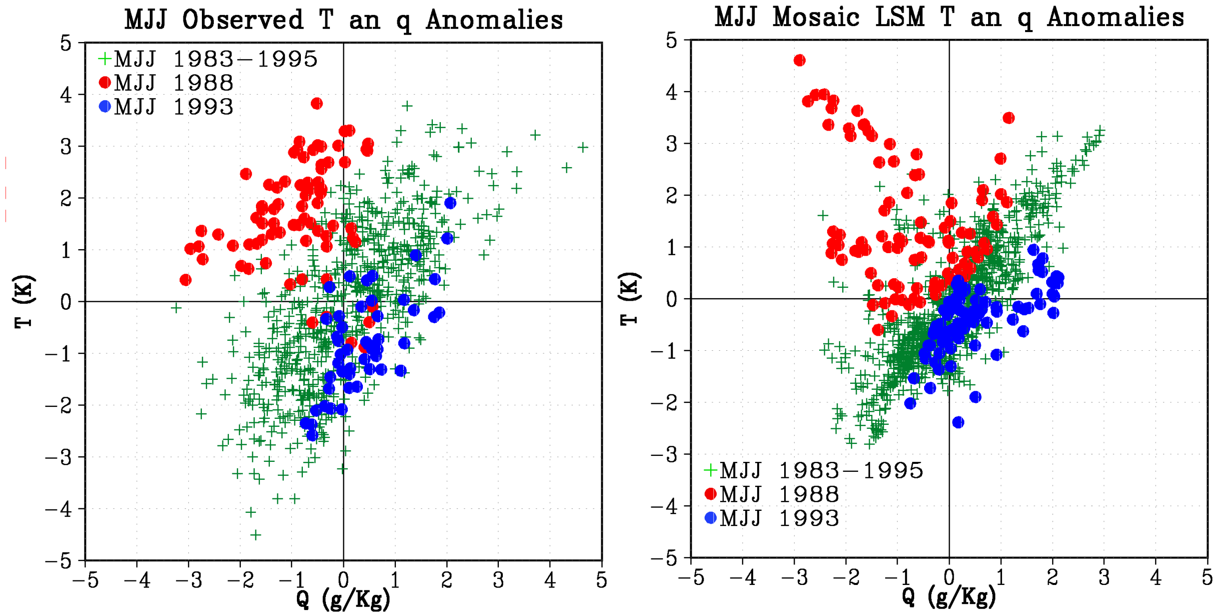


Figure 1: Schematic diagram of OLGA (Off-line Land-Surface Global Assimilation System). Output is used from the atmospheric assimilation system to provide forcing terms for the land-surface model (LSM) embedded in OLGA. These forcing terms might be fused with other types of observations to address known biases in the atmospheric assimilation. Land-surface observations are then assimilated into the LSM using PSAS as the objective analysis algorithm. Depending upon the application, the results from this off-line assimilation might be archived for research purposes, or passed back to the assimilation system. While the ultimate goal is a complete integrated surface atmosphere system, our current effort addresses the problem in an off-line matter to allow flexibility in the study of sensitivities before the components are completely coupled.



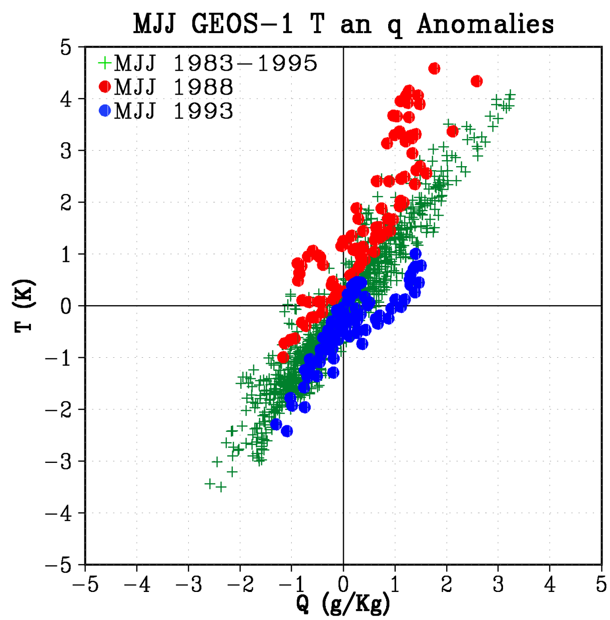


Figure 2. Scatter of temperature and moisture anomalies in observations (Gaffen and Ross, 1999), OLGA (Mosaic) and GEOS-1 DAS. Each point represents a grid point (or station) monthly mean difference (MJJ only) from the 1983-1995 period average in the Central United States.

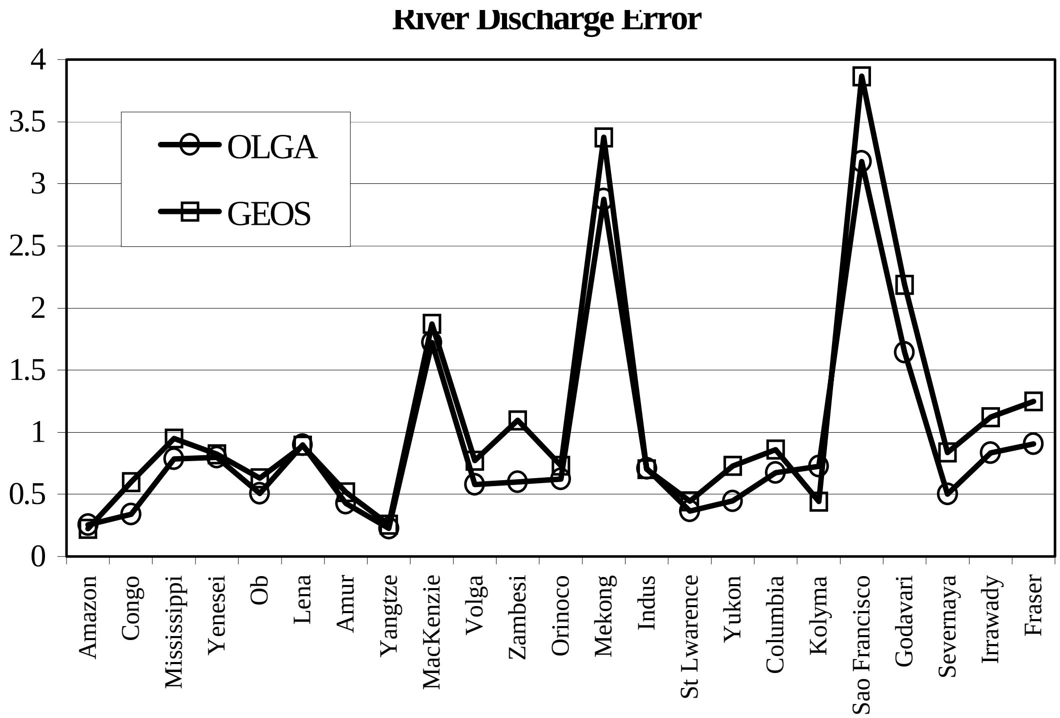


Figure 3 Normalized river discharge error from OLGA and GEOS-1 DAS. Rivers sorted by decreasing basin area.

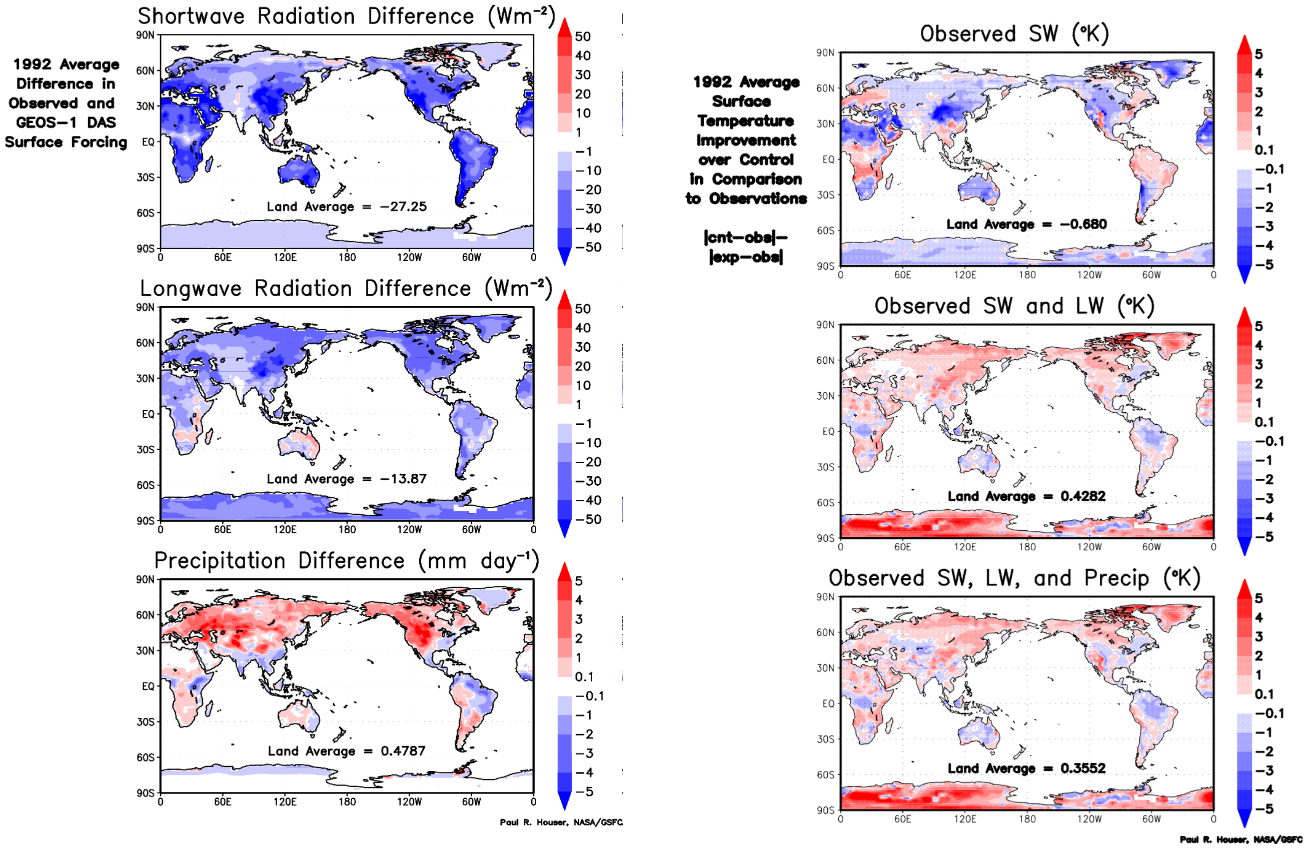


Figure 4: The influence of observed forcing on global land surface predictions.

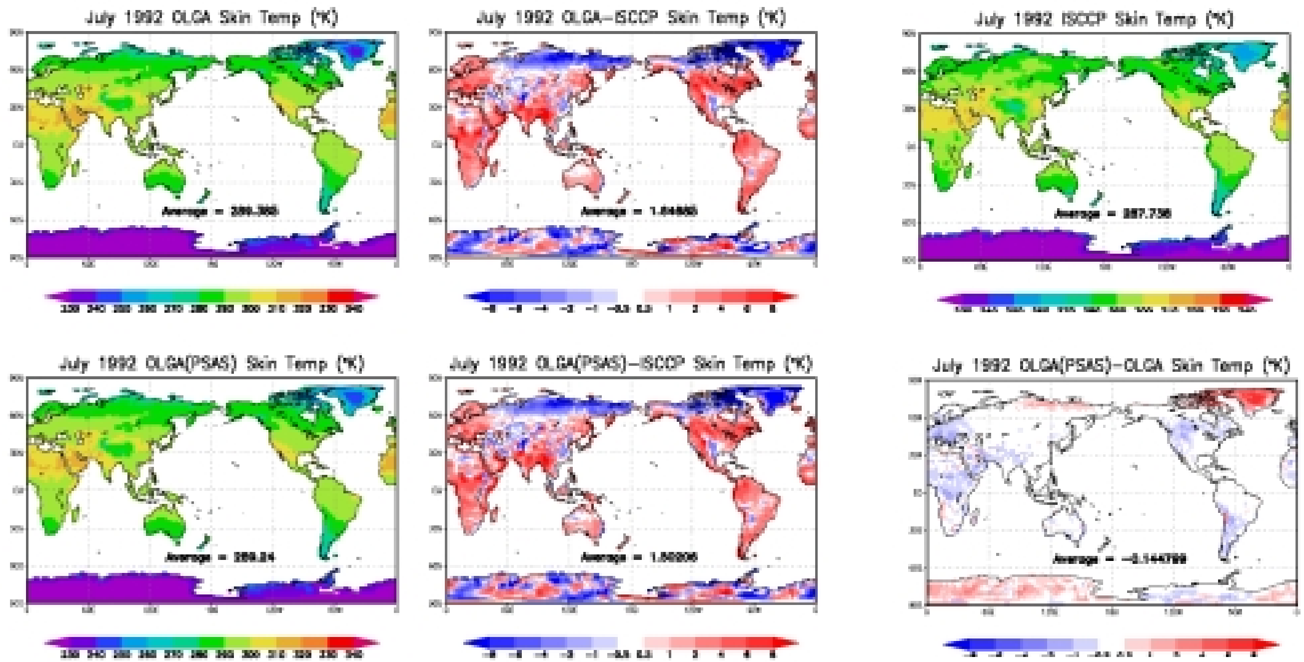


Figure 5: Improved land surface states through assimilation on ISCCP land surface temperature.